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REPORT BY THE

Comptroller General

OF THE UNITED STATES

Relative Performance Of Defense And Commercial Communications Satellite Programs

Military communications satellite programs have been more costly, more technically difficult, and harder to manage than the commercial programs. The military programs' technical problems also have been compounded by launch vehicle failures to attain orbit.

The report was prepared at the request of the former Chairman, House Committee on Appropriations. HSE00300

LCD-79-108
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COMPTROLLER GENERAL OF THE UNITED STATES
WASHINGTON, D.C. 20548

B-168707

The Honorable Jamie L. Whitten
Chairman, Committee on Appropriations
House of Representatives

HSE00300

Dear Mr. Chairman:

In response to the former Chairman's October 24, 1978, letter, we have reviewed the cost and schedule experiences of both the Department of Defense's and the commercial sector's communications satellite programs. The programs reviewed are listed on page 10 which also presents the more detailed results of our analyses. The contents of appendix I, which are summarized below, were presented to your staff on April 19, 1979.

MILITARY SATELLITES ARE MORE COSTLY THAN COMMERCIAL

The average costs to develop, procure, and launch the military's latest generations of communications satellites have been greater than the most expensive commercial satellites. (See p. 12.) The military's higher costs have been the result of (1) more sophisticated satellite designs, (2) more costly developmental programs, and (3) developmental schedule delays that require alternative satellite procurements for operational "gapfillers." (The gapfiller costs are additive, but for a fair treatment of average relative costs, they are not included in our analyses.)

In short, the latest military satellite developments have been technically difficult and, consequently, harder to manage. In contrast to the military experiences, the commercial sector's lower costs have resulted from more conservative and, therefore, more manageable satellite developments.

Unique military requirements increased satellite complexity

In general, the designs of the Initial Defense Communications Satellite Program (IDCSP) and the Defense Satellite Communications System, Phase II (DSCS II), satellites were comparable in complexity to the most sophisticated commercial satellites of the same generations. Both sectors' satellites were designed to provide appropriate communications capacity to a host of military and commercial users, and the satellite designs at those times were developed within the then existing state of the art. The specific amounts of capacity available depended upon the users' preferred methods of using the satellites (modulation techniques). Nevertheless, those earlier generation satellite designs evolved in a similar fashion. Appendix II discusses these programs in more detail.

The military's latest generation of communications satellites--the DSCS, Phase III (DSCS III), and the Navy's Fleet Satellite Communications (FLTSATCOM) satellites--have extremely sophisticated designs in comparison with all other communications satellites. These designs include new technologies that are not within the existing state of the art for communications satellites. For example, the DSCS III and FLTSATCOM designs stress overall "hardening" to enhance their chances of surviving in orbit during periods of nuclear conflict. The DSCS III satellites will employ a new antenna technology that has not been flown on earlier satellites, and the FLTSATCOMs are designed to meet the most stringent of the military's communications requirements. All of these unique requirements imposed on the satellite designs have contributed to the development of new technologies, but they have also increased the potential for cost increases and schedule slippages in the military's programs.

Developmental problems

The military's two latest generation of communications satellites--FLTSATCOM and DSCS III--have experienced high costs and schedule delays due to developmental problems. The problems are directly related to the high level of design sophistication required for these satellites. Although the FLTSATCOM development problems have been resolved, the DSCS III development is still having difficulties. The DSCS II program ran into development problems also, but because of this satellite's relatively uncomplicated design, its problems were readily corrected and the operational system was only slightly affected. However, the DSCS II program suffered severe setbacks due to unsuccessful launch attempts. The combination of launch and design problems delayed the full DSCS II operational system by about 10 years.

The commercial sector has also experienced developmental problems--namely, the International Telecommunications Satellite, Phase III (INTELSAT III), and the Maritime Satellite (MARISAT) developments--that were more manageable than the military's developments, and therefore resulted in no appreciable cost increases. The reasons for the two sectors' varied experiences follow.

The stringency of the Navy's and the Air Force's communications requirements for the FLTSATCOM satellites caused technical difficulties in the development program. These difficulties caused cost overruns and schedule delays. (See pp. 13, 15, and 22.) As a result of the schedule delays, the Navy funded a lease arrangement with the MARISAT owners to fill the operational gap in the FLTSATCOM program. The Navy paid $138 million for the lease in addition to FLTSATCOM's basic costs and overruns. The lease costs are not reflected in our FLTSATCOM figures, however.

The FLTSATCOM development was performed using a cost-reimbursable type of contract. The Government's costs overran by more than $80 million (over 200 percent), before the technical difficulties were resolved. According to a Navy audit of the development, it was incorrectly assumed that the FLTSATCOM design was within the existing state of the art. This position attests to the high level of sophistication in the satellite's design. It also implies a degree of uncertainty with the military's control of the development.

The DSCS III development is presently encountering technical difficulties, schedule delays, and cost overruns. (See pp. 13, 15, and 22.) According to the Air Force, the most significant contributor to the development's cost increases is the redesign effort required to meet the military's survivability requirements and to compensate for the satellite's increased weight (a consequence of the redesign).

In contrast to FLTSATCOM's cost-reimbursable contract, the DSCS III development is being performed under a fixed-price type of arrangement. Theoretically, any cost growth under this type of contract should affect only the contractor unless, of course, the fixed-price ceiling to the contract is lifted.

The DSCS III development contractor is expect d to overrun his own costs by about $28 million. The Department of Defense has requested about $24 million in fiscal year 1980 funds to obtain parts for DSCS III production satellites from the development contractor. The requested amount is based on an estimate of costs that the contractor provided to the Department of Defense. No specific listing of the parts by type, date of need, or cost has been provided to support this estimate. The absence of such justification increases the potential for cost growth in the DSCS III program. A similar situation occurred in the FLTSATCOM program.

For example, in the Navy's audit of the Air Force's management of the FLTSATCOM development contract (see pp. 22 and 23), the Navy pointed out that the costs for long leadtime (production) parts grew from $5.3 million to more than $50 million, and the development contractor had offered no precise inventory of the required long leadtime hardware. In subsequent hearings by your Committee, it was established that these funds intended for production use were funneled into the development, which was having overrun problems.

In testimony before your Committee in April 1979, Defense officials said that the contractor is working on preparing a list of DSCS III long leadtime items. The list was expected to be available in late summer 1979. The Committee may wish to make Defense's use of the funds contingent upon completion of the long lead item inventory.

Attendant to the DSCS IIIs schedule delays, the program is about to experience another appreciable cost growth. As a result of the slip in schedule, it appears that the military is concerned about a possible "gap" in DSCS communications. Therefore, Defense plans to spend about $100 million over the next 3 years to procure two more DSCS II satellites, which could be used to fill the gap if it occurs. We have not included these additional DSCS costs in our figures, however.

Other military and commercial satellite programs have encountered extensive problems during their development phases. However, these problems were not critical to the maintenance of the operational systems, as they are now for the DSCS III and FLTSATCOM programs. For example, the INTELSAT III, DSCS II, and MARISAT developments had design problems that led to schedule delays. (See pp. 15, 16, and 19.) Since their designs were within the existing state of the art, their problems were quickly alleviated. Also, since the DSCS II development began the military's first operational system (the earlier system was experimental) the early development problems did not seriously affect system operations.

The MARISAT's technical problems were found mainly in the Navy's dedicated portion of the satellite. As stated earlier, the MARISAT served as the Navy's gapfiller for FLTSATCOM. According to the MARISAT owners, the contracted schedule was influenced by the urgency of the Navy's requirements; however, the probability of late delivery of the satellites was very high. The delivery was indeed late, but it was timely enough to fill in for FLTSATCOM.

In all cases but one (INTELSAT III), where technical problems led to significant schedule delays and cost overruns, it was the need to satisfy stringent military requirements that contributed most to these difficulties. For INTELSAT III, the problems encountered proved to be manageable, and the operational system was not affected. The military's development problems have not been as easily managed, and they have consequently caused the military's high costs.

MILITARY COST GROWTH GREATER THAN COMMERCIAL

Unplanned for cost growth in the military contracts have ranged from 15 to about 238 percent over the original prices. (See p. 13.) In contrast to the military, the highest cost growth of this type in any commercial contract was about 11 percent. The specific reasons for the varied costs between the two sector's contracts are explained in appendix I. In general, it appears that the military's cost growth results mainly from development-related overruns.

According to the commercial satellite owners and manufacturers (who also build the military satellites), all of the commercial development and production contracts are of the fixed-price type. This is also true for the military's contracts, with the exception of the FLTSATCOM development. However, the major difference between the two sectors' contracts is that the commercial design requirements are appropriately fixed by the time of the contract award. This is not the case for the military contracts, which we discuss in appendix II.

The uncertainty of the DSCS III and FLTSATCOM designs are reflected in the large number of changes to the development contracts. This is evidenced by over 200 changes for FLTSATCOM, over 50 changes for DSCS III, and over 350 amendments to the DSCS II contracts. On the commercial side, the highest number of contractual changes observed was 27. It therefore appears that the commercial practice of fixing the design before contract award, along with less complexity involved with the design, has contributed greatly to the commercial sector's success at holding down cost and schedule overruns.

Program cost growth

One more point can be made about the military programs' cost growth. As shown on page 14, all of the military's programs have incurred from 35 percent to over 200 percent growth in costs since their inception. We were not afforded similar types of commercial documentation to assess their programs' relative cost increases. Nevertheless, the figures indicate the military's optimism, with respect to costs, during the initiation periods for each program. Consequently, decision-makers may have not appropriately considered the potential costs for each program.

SCOPE

During our review we examined pertinent background information, contract data, and Department of Defense decision documents. We interviewed officials of the Departments of Defense, the Air Force, and the Navy, Washington, D.C., and Los Angeles, California; RCA, Piscataway, New Jersey; Western Union, McLean, Virginia; and COMSAT and COMSAT General Corporation, Washington, D.C. We also interviewed officials at Hughes Aircraft Company, El Segundo, California; and TRW, Inc., Redondo Beach, California.

The satellite costs were derived from the spacecraft development and procurement contracts and funds expended under those contracts. The DSCS III costs are estimates using constant fiscal year 1977 dollars, which were provided by the Department of Defense. All other costs were actually expended under the reviewed contracts, which in some instances were adjusted for inflationary increases. The COMSAT and COMSAT General Corporation officials allowed us to verify their satellite costs by examination of their contracts with satellite manufacturers. We were not allowed similar verification of the RCA and Western Union contracts. The launch costs were derived from all costs associated with launching the vehicle, excluding computer software costs. The launch associated costs were provided by both sectors' officials and were not verified by us.

Because of the Committee's urgent reporting requirements, there was insufficient time available for us to obtain formal comments from the Department of Defense on this report. Defense officials with whom we discussed the report declined to provide oral comments.

As requested by your office, unless you publicly announce its contents earlier, we plan no further distribution of this report until 30 days from the date of the report. At that time we will send copies to interested parties and make copies available to others upon request.

Sincerely yours,

R. F. Keller

ACTING Comptroller General
of the United States

RELATIVE PERFORMANCES OF COMMERCIAL VS. MILITARY COMMUNICATIONS SATELLITE PROGRAMS

SATELLITE PROGRAMS STUDIED

Military	Type	Purpose
IDCSP	Experimental	
DSCS II	Global	Increased capacity
DSCS III	Survivability	Anti-jamming
FLTSATCOM	Survivability	Nuclear hardening
Commercial		
INTELSAT I-IV-A	International	Increased capacity
Additional commercial common carrier service		
MARISAT	Maritime global	
COMSTAR	Domestic	
WESTAR	Domestic	
SATCOM	Domestic	

CHARACTERISTICS OF COMMUNICATIONS SATELLITES

Series	Height (feet)	Weight (pounds)	Parts count	Design life (years)
INTELSAT I	2.0	150	unknown	1.5
INTELSAT II	2.4	357	6,000	3.0
INTELSAT III	3.4	647	10,000	5.0
INTELSAT IV	10.3	3,120	22,000	7.0
INTELSAT IV-A	22.9	3,340	23,000	7.0
SATCOM	4.5	2,000	18,000	8.0
WESTAR	11.6	1,233	unknown	7.0
MARISAT	12.2	1,445	15,000	5.0
COMSTAR	20.0	3,348	20,000	7.0
IDCSP	2.7	100	5,000	1.5
DSCS II	13.0	1,150	35,000	5.0
DSCS III	6.8	2,400	100,000	10.0
FLTSATCOM	16.7	4,100	59,000	5.0

MILITARY AND COMMERCIAL

SATELLITE

AVERAGE UNIT COSTS

Satellite series	Date of first contract	Number of satellites Procured	Launched	Orbited	Average per unit costs (note a)
					(millions)
INTELSAT:					
I	1964	2	1	1	$ 8.6
II	1965	5	4	3	7.7
III	1966	8	8	5	11.9
IV	1968	8	8	7	31.7
IV-A	1973	6	6	5	46.5
MARISAT	1973	3	3	3	26.4
COMSTAR	1973	4	3	3	41.5
SATCOM	1973	3	2	2	36.8
WESTAR	1972	3	2	2	19.5
IDCSP	1962	36	34	26	7.7
DSCS II:	1969				
C-1		6	6	4	28.5
C-2		10	6	4	38.5
DSCS III:	1974				
Development		2	0	0	b/82.1
Production		12	0	0	b/42.0
FLTSATCOM:	1972				
C-1		3	1	1	94.4
C-2 (note c)		2	0	0	d/80.2

a/Average derived by dividing total satellite and launch costs by number of satellites produced.

b/Estimated to completion by Defense.

c/Development cost distributed over two production contracts.

d/Contract just awarded.

EXCESS OF COSTS OVER BASIC CONTRACT PRICES

		Excess due to				
		Options	Contract changes			
Satellite series	Basic price		Non-option spacecraft	Percent	Other	Percent over basic
	(millions)					
INTELSAT:						
I	$ 7.8	-	-		0.3	4
II	10.3	2.3	-		0.6	6
III	32.0	11.7	-		3.4	11
IV	54.8	21.8	-		3.7	7
IV-A	59.8	-	41.1	68	6.2	10
MARISAT	36.2	0.3	-		0.1	0
COMSTAR	55.9	-	-		1.3	2
SATCOM	25.3	4.1	-		0.7	3
WESTAR	19.6	2.4	-		0	0
IDCSP:						
C-1	23.5	-	-		7.7	33
C-2	3.6	-	-		unknown	-
C-3	8.2	-	-		unknown	-
DSCS II:						
C-1	37.6	28.0	-		10.0	27
C-2	73.2	1.5	70.1	95	15.2	20
DSCS III:						
Development	76.5	8.5	-		20.0	26
FLTSATCOM:						
Development	35.9	5.4	-		85.6	238
C-1	52.2	17.8	44.9	86	8.0	15
C-2	53.5	-	-		-	-

MILITARY COST GROWTH FROM ORIGINAL ESTIMATE TO DATE

Satellite series	Decision coordinating paper estimate	Costs to date	Difference amount	Percent difference
	-------------(millions)	-------------	-------------	
IDCSP	$ 23.5	$ 43.0	$ 19.5	83
DSCS II	104.0	235.7	131.6	127
DSCS III	367.4	a/496.8	129.4	35
FLTSATCOM	100.0	303.3	203.3	203

a/Estimated to completion.

ACTUAL VS. ORIGINAL DELIVERY SCHEDULES

Series	Total delivered	Early or on time	Months late in delivery: 1-9	10-18	19-27	28-36	37-45
	Number of satellites						
Commercial:							
INTELSAT I	2	1	-	-	-	-	-
INTELSAT II	5	1	3	1	-	-	-
INTELSAT III	8	1	4	3	-	-	-
INTELSAT IV	8	4	4	-	-	-	-
INTELSAT IV-A	6	2	4	-	-	-	-
MARISAT	3	-	-	3	-	-	-
COMSTAR	4	-	4	-	-	-	-
SATCOM	3	2	1	-	-	-	-
WESTAR	3	3	-	-	-	-	-
DOD:							
IDCSP	36	a/unknown	-	-	-	-	-
DSCS II	b/16	10	2	-	-	2	2
DSCS III	c/ D	est. late	-	D	-	-	-
FLTSATCOM	d/ D	-	-	D	-	-	-
	b/ 5	2	1	2	-	-	-

a/Schedule information not available.

b/Four undelivered satellites with estimated dates.

c/Developmental satellite's estimated date.

d/Developmental schedule slippage.

Descriptions of the changes to commercial contract prices and delivery dates follow.

INTELSAT satellites

The Communication Satellite Corporation's (COMSAT's) experience in meeting expected costs and delivery schedules for the INTELSAT series has varied. Its least complicated program was INTELSAT I, in which the final cost exceeded the original contract price by about 4 percent. Since the contractor had already started work on the satellites before the contract was actually signed, by the time the contract was finalized, everyone had a good idea of what cost to expect.

The cost increase for the INTELSAT II series was somewhat larger than that for INTELSAT I. The largest component of the $2.9 million increase was $2.3 million for the fifth satellite, one that was never launched. This satellite had been bought as insurance against further delays in the delivery of INTELSAT III spacecraft. A COMSAT official attributed the delivery delays of the INTELSAT II to a decision midway through the INTELSAT II project to develop a higher performance antenna.

The satellites in the INTELSAT III series were also to include a newly designed antenna, so that additional satellite power would be radiated toward the Earth rather than into space. In the new design, an electrical system for aiming the antenna was to be used instead of a mechanical one. When the difficulties in developing the electrical system became too great, however, the designers changed to a mechanical system. According to a COMSAT official, COMSAT did not reimburse the satellite contractor for extra costs related to these problems because the contract did not call for reimbursement. However, when COMSAT needed more INTELSAT III satellites than it had bought originally, it paid an amount substantially higher than the options in the original INTELSAT III contract. If COMSAT had bought the seventh and eighth satellites by mid-1967, before the options expired, it would have paid the option prices of about $1.9 million and $1.8 million, respectively. According to a COMSAT official, the options were not exercised then because circumstances did not require it. When circumstances changed and COMSAT did buy the satellites in 1969, it paid $3.8 million and $7.5 million.

The cost of these two satellites accounted for about three quarters of the $15.1 million differences between the original and amended contract prices. Other items included in the differences were about $0.4 million to exercise an option for a fourth telemetry and command set, about $1.4 million for launch support services, and over $1.6 million--in addition to the price of the first six flight spacecraft--for mutually agreed upon work outside the scope of the contract.

Due to the problems in INTELSAT III's development, delivery of the satellites was later than originally scheduled. Also, because of launch vehicle malfunctions and spacecraft performance deficiencies, much of the maximum possible amount in incentives for satisfactory spacecraft performance was not paid to the contractor.

Like INTELSAT III, INTELSAT IV had a significantly greater amended contract price than the basic contract price. Unlike INTELSAT III, however, the option for the four additional INTELSAT IV spacecraft was exercised for the amount specified in the original contract. This amount, plus the cost of launch support services for the four extra satellites, accounted for about $21.8 million of the total $25.5 million difference between the two contract prices. Of the remaining $3.7 million difference, over $2.9 million is accounted for by the following changes and additions:

--A thermal test to provide greater confidence in spacecraft performance.

--A fourth ground station telemetry and command equipment set.

--Changes to the apogee motors.

--The addition of a third Earth sensor and other equipment in each flight spacecraft.

--Engineering changes to the spacecraft.

--A study of derivative extended capacity.

The INTELSAT IV contract had the most amendments (27) in the INTELSAT series. According to a COMSAT official, COMSAT rather than the contractor, initiated most of the changes. Several of the changes incorporated delays in satellite delivery dates. For instance, the contractual delivery date of one satellite was set back 9 months. The dates of two other satellites, however, were moved forward 12 and 20 months.

For several of the INTELSAT IV satellites, the actual delivery dates bore little resemblance to the contractual dates. Although one satellite was technically delivered in February 1971 (around the time the contract specified), it was not acceptable to COMSAT. After the satellite was already assembled, problems were noted which could be fixed only by taking the satellite apart. The contractor ran tests and asserted that the satellite met all contractual requirements. Nevertheless, COMSAT felt the spacecraft was not suitable for flight. COMSAT sent the satellite to storage with the idea of either taking the matter to court at a later date or having the satellite disassembled and the problem corrected. COMSAT eventually chose the latter course, and the satellite was launched in 1975.

The contractual delivery dates for some of the other satellites had been amended to modify the spacecraft design, allow additions to be made to the satellites, and include tests to provide greater confidence in spacecraft performance. According to a COMSAT official, the dates for still other satellites' deliveries had been set far into the future as a concession to the contractor. The contractor, in turn, had made concessions to provide COMSAT with higher performance spacecraft.

The cause of most of the $47.3 million cost change in the INTELSAT IV-A contract was the decision to buy three more spacecraft and their launch support services for $41.1 million. The amendment for the additional satellites was a departure from COMSAT's usual satellite acquisition strategy. Instead of containing strictly fixed cost provisions, it included an inflation adjustment clause. This clause resulted in $5.3 million of the remaining $6.2 million cost difference. According to a COMSAT official, COMSAT adopted the inflation adjustment provision with the thought it would bring a better price in the long run.

Although relative to the basic INTELSAT IV-A contract price, the other amendments were minor. Nevertheless, additions to the satellites called for by one amendment slightly extended the contractual delivery dates for the first three satellites. The 7-month slip in the actual delivery date of the third satellite was due to the various technical problems and delays in completing testing.

MARISAT

The three MARISAT satellites were delivered to COMSAT General about 1 year behind schedule. The time between the MARISAT contract's effective date and the actual dates of delivery turned out to be over 50 percent more than the 17 to 23 months that was in the basic contract. According to COMSAT, the urgency of Navy requirements influenced the delivery period in the original contract. Since designing and producing a new spacecraft series normally takes 2 to 3 years for the first delivery, the probability of late delivery on the first MARISAT was very high.

COMSAT General attributes the lateness in delivery in part to component problems discerned during the development program. For example, the contractor had to replace already built-in parts and change manufacturing methods to fix problems encountered during environmental tests.

A second major reason for delayed delivery was the discovery, late in the program, of persistent large and unstable levels of spurious signals (intermodulation products) generated within the transponder constructed for Navy service. Since these spurious signals were caused by a variety of sources, a number of corrective measures were necessary to reduce and stabilize them. These measures included shielding and cleaning certain spacecraft surfaces, avoiding metal-to-metal contact, soldering cables to stabilize their mechanical contact, and using and avoiding certain materials and manufacturing processes. In addition, since these changes were made late in the program, considerable retesting was required.

In spite of the difficulties leading to the delivery delays, the amended contract price exceeded the original by less than 1 percent.

COMSTAR

COMSAT General's COMSTAR program also experienced little cost increase by some delivery delays. While contract amendments resulted in only about a 2-percent growth in cost, three of them did cause slippage in the contract delivery dates, extending the date of one satellite delivery by 5 months. These amendments were for additional hardware and test measurements. In addition, due to other problems, three of the satellites were actually delivered between 1 to 3 months after the amended contract dates. These slippages, though, were unlike the magnitude of the MARISAT's schedule slippage.

SATCOM

Of the $4.8 million difference between SATCOM's basic and final contract prices, $4.1 million resulted from RCA exercising a provision for the contractor to actually place the satellites in orbit. This provision had been planned all along, but the details had not been worked out when the contract was signed. Because the work to be done was slightly changed from what was initially planned, the $4.1 million figure was higher than earlier contemplated.

According to an RCA official, the late delivery of SATCOM II was not a slippage problem. Rather, RCA purposely decided to delay delivery so that SATCOM I could undergo additional tests before SATCOM II was officially accepted. Also, according to RCA officials, SATCOM III was technically delivered on time, although RCA did not take title. At delivery, the satellite was unassembled.

WESTAR

According to Western Union officials, the only adjustment to the basic WESTAR contract price and delivery dates was the exercise of a $2.375 million option to buy components for a fourth spacecraft.

The reasons for both the cost and schedule variances on the Defense side follow.

IDCSP changes

The contract information for the IDCSP program was destroyed after 7 years in storage. Consequently, cost data was available on only the first contract to the Philco-Ford Corporation. No schedule information was available. The known cost growth in IDCSP was mainly attributed to the replenishment of eight satellites that were lost during one launch failure.

DSCS II changes

The initial DSCS II contract called for the design and fabrication of a development model. Defense decided to initiate production of six satellites about 5 months later. This action resulted in Defense's exercising of the contract option which provided about $28 million more for these production spacecraft.

Satellites one's and two's deliveries were delayed by changes to the basic DSCS II development design, which were incorporated into the subsequent flight models. During their orbital operations, the first two flight satellites failed due to technical difficulties. Consequently, the subsequent satellites in this series were redesigned to compensate for the technical failures and to ensure that similar orbital problems did not reoccur. Satellites three and four incurred about a 19-month schedule slip as a result of that redesign.

The third and fourth satellites suffered partial communications failures in orbit while the fifth and sixth satellites were being built. The designs of both five and six were altered to compensate for the first and second pairs of satellites' difficulties. Consequently, the schedules for satellites five and six were slipped by almost 4 years.

As soon as most of the technical difficulties with the first DSCS II satellites were successfully compensated for in the redesigns, the final DSCS II design was completed. The schedules of satellites 7 through 12 were then accelerated and they were all delivered either on time or about 1 month early. The contractor was compensated for accelerating the schedule, and this action contributed to the eventual cost growth of the contract.

Four DSCS II satellites were lost as the result of two launch failures. The Air Force's Space and Missile Systems Organization (SAMSO) contracted with TRW, Inc., in April 1977 to provide four additional satellites, for a total procurement of 16. About $69.6 million was provided for this purpose. In the same contractual arrangement, SAMSO contracted for long leadtime parts for satellites 17 and 18. The funds provided were about $0.5 million. The additional cost growth for the first 12 satellites was attributed to (1) $1.5 million for resolving the third through sixth satellites' technical problems, (2) $1.5 million for launch options, and (3) about $20 million for over 350 amendments to the two contracts to include $4.9 million for producing high level transmitter tubes for satellites 13 through 16, about $3.7 million to accelerate long leadtime production tasks and satellite deliveries, and about $1.5 million for economic price adjustments to the contracts. About half of the $20 million was incurred in small amounts that ranged anywhere from one thousand to several hundred thousand dollars each.

DSCS III changes

The DSCS III schedule changes only reflect one estimated change. Also, since the DSCS III developments are proceeding under a fixed-price type of contract with incentive fee arrangements, the cost growth affects only the contractor, unless the contract ceiling is lifted. The contractor may receive additional funds in the development phase, if on-orbit performance incentives are awarded by Defense and the development contractor is tasked to procure long leadtime production hardware in his program.

The DSCS III development is presently incurring cost and schedule overruns. SAMSO has predicted that the contractor will overrun his costs by about $28 million and his schedule by about 1 year for the first demonstration flight satellite.

FLTSATCOM changes

Development of the FLTSATCOM qualification model was hampered by stringent Air Force and Navy communications requirements. The resulting numbers of closely spaced communications channels required aboard each satellite allowed insufficient isolation between channels, and as a consequence, radio frequency intermodulation products were generated within its channels. TRW was required to initiate a major redesign effort to reduce the effects of the interference. Since the design effort was under a cost-reimbursable type of contract, Defense experienced about an $85 million cost growth in the development program. About $5 million of the $85 million was provided to exercise an option for long leadtime production parts and for storage. Therefore, about $80 million was cost growth not provided for in the original development contract.

The Navy audited the FLTSATCOM program and reported the results in a March 31, 1977, document entitled "Audit Report on Fleet Satellite Communications Program." The report is classified, but the pertinent facts are unclassified. According to the report, the following actions resulted in the cost and schedule growth of the FLTSATCOM program:

--It was incorrectly assumed that the FLTSATCOM development was within the state of the art.

--Contractors had already bidded on a fixed-price basis for the development, but SAMSO changed the type to cost-reimbursable. The contractors' dollar estimates were significantly lower than their earlier fixed-price estimates. SAMSO eventually capped the cost-reimbursable type of contract with a ceiling. The new capped reimbursable contract then resembled the earlier fixed-price version.

--The stringency of the Navy's and Air Force's communications requirements aboard the same satellite caused technical difficulties with the development, which contributed to the cost and schedule overruns.

--Perceived problems leading to cost growth were slipped to the appropriations "out years" to allow consistent funding within the near term. Cost growth occurred in the out years as the program period was expanded.

--The development schedule was influenced by Defense's "perceived need to meet operational requirements."

--Long leadtime costs grew from $5.3 million to more than $50 million (at the time of the Navy's audit), and the contractor offered no precise inventory of the long leadtime hardware. Defense did not establish a stable FLTSATCOM design before initiating production.

--Since the program was an interservice one, it received high visibility from high levels of management in both services and in Defense. This micromanagement by Defense officials ultimately eroded the control of the program managers.

COMMERCIAL AND DEFENSE COMMUNICATIONS SATELLITE PROGRAMS

COMMERCIAL SATELLITE PROGRAMS

In the past 15 years, commercial communications satellites have become larger in size and capacity, more sophisticated, and more expensive to build. Therefore, predicting the costs and delivery dates for individual satellites has become very challenging for the commercial sector.

COMMERCIAL SATELLITES AND INCREASED COMMUNICATIONS TRAFFIC

The world's first commercial communications satellite, Early Bird, was put into service in 1965. Succeeding satellites have met growing communications traffic with greater communications capacity, longer design lives, and new advances in communications technology. The Congress authorized COMSAT to offer international communications satellite services throughout the 1960s. COMSAT was formed in 1963 to carry out a congressional mandate to establish a global commercial communications satellite system in cooperation with other countries. In the 1970s, COMSAT General, Western Union, and RCA launched other communications satellites to provide additional services.

Satellites in the global system

COMSAT offers communications service between the United States and foreign points through the satellites of the INTELSAT organization. INTELSAT owns, operates, and maintains the satellites in the global communications system, with COMSAT owning about a 25-percent investment share in INTELSAT. In all, five series of INTELSAT satellites have been launched in the past 15 years--the INTELSATs I (Early Bird), II, III, IV, and IV-A.

Each satellite series contained greater communications capacity and more advanced technology than its predecessor. Early Bird made live transoceanic television possible for the first time and increased telephone capacity across the Atlantic by nearly two-thirds. In 1967, its successor, INTELSAT II, introduced a multipoint communications capability and extended satellite coverage to more than two-thirds of the world. INTELSAT III satellites, first launched in 1968, established the global system. They allowed the simultaneous transmission of telephone, television, telex, data, and facsimile. INTELSAT IV satellites were first launched in 1971 and were designed to meet global system requirements through the first half of the 1970s. To meet the increased requirements of the latter half of the 1970s, INTELSAT IV-A satellites will be used. These are modified INTELSAT IVs, rather than newly designed satellites. The first IV-A was launched in 1975. Within both the INTELSAT IV and IV-A series, options for additional satellites were exercised because communications traffic was growing faster than COMSAT officials had anticipated. The following chart summarizes the changes that have occurred within the INTELSAT series.

Characteristics of INTELSATs I Through IV-A

Satellite series	Satellite height (feet)	Satellite weight (lbs. at launch)	Satellite capacity (simultaneous phone calls) (note a)	Design life (years)
INTELSAT I	2.0	150	240 or 1 T.V. channel	1.5
INTELSAT II	2.4	357	240 or 1 T.V. channel	3.0
INTELSAT III	3.4	647	1,500 or 4 T.V. channels or combinations of these	5.0
INTELSAT IV	10.3	3,120	4,000 and 2 T.V. channels	7.0
INTELSAT IV-A	22.9	3,340	6,000 and 2 T.V. channels	7.0

a/Actual capacity varies, depending on traffic conditions.

To illustrate how much communications traffic has increased since Early Bird, COMSAT cites the following statistics:

--In 1977, COMSAT was leasing 5,315 half-circuits full time to its U.S. communications carrier customers, compared to 66 in 1965. (A half-circuit is one end of a two-way communications link.)

--At the end of 1977, 96 countries, territories, or possessions, were full-time users of satellite services with COMSAT, as opposed to 13 in 1965.

COMSAT General's satellites

In 1973, COMSAT established the COMSAT General Corporation as a wholly owned subsidiary to carry out COMSAT programs not related to the global INTELSAT system. Two of these programs are MARISAT and COMSTAR.

COMSAT General heralded the MARISAT satellite system as the most significant maritime communications step since the arrival of the wireless at the turn of the century. Standing 12 feet 4 inches high, weighing 1,445 pounds at launch, and having a 5-year design life, each of the three MARISAT satellites provide telex, data, and telephone communications between the shore and locations at sea. Unlike traditional maritime communications, MARISAT is essentially unaffected by weather or ionospheric conditions, allowing fast and dependable communications in complete privacy, 24 hours a day. MARISAT service began in 1976.

In addition to providing commercial service, the MARISAT satellites are also designed with communications channels specifically for the Navy's use. Since the Navy's FLTSATCOM development program was experiencing some technical difficulties at the time of MARISAT's inception, the Navy funded the lease of special MARISAT communications service for use by its fleet. This interim service for the Navy's program is commonly called the "gapfiller."

The COMSTAR satellites are the first to be used for nationwide message telephone service. Their capacity is leased to the American Telephone and Telegraph Company for domestic communications. Employing advanced techniques, each of the four delivered satellites can relay over 18,000 two-way telephone calls simultaneously, has a 7-year design life, is 20 feet high, and weighs 3,348 pounds at launch. The first COMSTAR was launched in 1976.

For a better appreciation of the evolution of COMSAT and COMSAT General satellites, see figure 1 on page 35.

RCA satellites

RCA's SATCOM satellites are designed to provide voice, television, and high speed data communications throughout the United States. Each of the three satellites has 24 channels, can simultaneously handle 24,000 one-way telephone messages or 24 color television programs, weighs 2,000 pounds, and has an 8-year design life. The 24-channel capacity is double that of similar satellites in orbit at the same time of SATCOM I's launch in December 1975.

In the planning stages for SATCOM, RCA felt that 24-channel satellites had certain economic and technical advantages over 12-channel satellites. One of these was the ability to meet the increased requirements of the three major commercial television networks for a program distribution service. When RCA originally considered using 12-channel satellites in 1971, it expected to launch only two of them initially and anticipated that increasing traffic and demand for additional services would eventually exceed satellite capacity. Even though SATCOMs I and II were actually launched with 24 channels each, RCA is now planning to launch SATCOM III, the third satellite in the original contract, to meet customer demand which is still growing. Figure 2 on page 36 shows RCA's SATCOM satellite, along with Western Union's WESTAR.

Western Union satellites

In 1974 Western Union launched America's first domestic communications satellites, WESTAR I and WESTAR II. A third WESTAR satellite has served as a ground spare and is scheduled for launch in August 1979. It will be launched as a potential replacement satellite since the first two satellites will soon be approaching the ends of their 7-year design lives.

The WESTAR satellites were designed to provide more communications flexibility and less cost for private communication systems. Each satellite has 12 channels, and each channel can relay either data at 50 megabits per second, one color television transmission, or 12,000 voice channels. The satellite weighs 1,233 pounds at lift-off.

DEFENSE SATELLITE PROGRAMS

Since the first experiments in 1962, the military's communications satellites have become increasingly larger both in size and capacity and have also become increasingly expensive to build. In addition to the larger capacities, sizes, and even greater satellite reliabilities (which incidentally are parameters similar to those desired by the commercial sector), the military communications satellites have been designed to satisfy orbital survivability requirements, such as improved performance against jamming and an ability to withstand the effects of physical attacks by other satellites and nuclear weapons. The latter effect is normally called "nuclear hardening" of the satellites. The survivability requirements for the military satellites set them apart from the commercial requirements for communications capacity and reliability.

MILITARY SATELLITES AND INCREASED COMMUNICATIONS AND SURVIVABILITY REQUIREMENTS

Defense's first attempt at developing its own communications satellites was in a program called "Project Advent." Following the termination of this experimental program, in 1962 Defense began developing the IDCSP system.

Program 572 or IDCSP was a successor to the first experimental use of satellites for military communications. SAMSO selected the Philco-Ford Corporation to develop and produce the IDCSP satellites. These satellites were to be launched eight at a time aboard the newly developed Titan-3C boosters. SAMSO was and still is responsible for managing the procurements of Defense's communications satellites.

The Congress questioned the need for Defense to pursue its own program for satellite communications, instead of leasing the service from the commercial sector. The Congress eventually agreed that, in this instance, the military appeared to have a unique and vital need to move ahead on its own.

Defense initiated IDCSP development in 1962 and then awarded the contract for production satellites to Philco-Ford in 1964. A total of 26 out of 36 procured IDCSP satellites were successfully launched into subsynchronous, equatorial orbits. 1/ Eight satellites were lost as the result of one launch vehicle failure in 1966. Two other satellites were never launched because of technical difficulties. Each of the IDCSP production satellites cost about $1.2 million. They were launched as follows:

Launch date	Number of satellites per launch
6/16/66	7
8/26/66	a/8
1/18/67	8
7/01/67	3
6/13/68	8

a/Did not attain orbit.

The main objective of IDCSP (aside from its experimental purpose), was to provide an emergency capability for supplementing the Defense Communications System and to improve its provision of minimum communications for military command and control purposes. During the Vietnam War, military communications support was provided by this system. By the end of 1975, five of the IDCSP satellites were still available on orbit for military use. One of the satellites which was launched in 1968 is still operating.

IDCSP satellites

The IDCSP satellites were relatively simple, single channel spacecraft that provided about 20 megahertz of bandwidth capacity. Each satellite was about 3 feet high. Figure 3 on page 37 shows the IDCSP satellite. The satellites used a common antenna structure for both transmitting and receiving communications signals. They weighed about 100 pounds at launch and had an average design life of about 1.5 years. However, as we mentioned earlier, one of these satellites is still operating after 11 years in orbit.

DSCS II

Defense procured six new satellites in 1969, as part of the next phase of the Defense Communications Satellite Program. These spacecraft, known as the DSCS II satellites, were

1/Revolving around the Earth at the Equator.

designed and fabricated by TRW, Inc., under the management of SAMSO and the Defense Communications Agency, which also had overall responsibility to Defense for IDCSP.

The DSCS II satellites were designed to have an improved communications capability over the IDCSP satellites by having four super-high frequency channels and employing Earth coverage and two spot beam antennas for greater communications flexibility and for a somewhat limited anti-jamming capability. Probably the more important contribution to military communications by the DSCS II satellites is that they were the first military communications satellites capable of maintaining synchronous, equatorial orbits. With the DSCS IIs, there was no longer a need for Defense to launch and simultaneously operate tens of subsynchronous satellites, such as those of IDCSP.

In October 1974 SAMSO awarded a DSCS II replenishment contract to TRW for six more satellites. In 1977 SAMSO amended that contract to allow TRW to provide 4 more satellites in addition to the earlier 12 that were procured. In addition, Defense has requested funding in its fiscal year 1980 budget to procure two more DSCS IIs, which would bring the total of satellites procured so far in this series to 18. The reasons for the additional DSCS II satellite procurements follow.

Since the inception of the DSCS II program in 1969, Defense has procured 16 and launched 12 DSCS II satellites. These satellites are launched two at a time aboard Titan-3C boosters. Until 1979, or about 10 years from the start of the DSCS II program, Defense had been unable to operate four DSCS II satellites in orbit simultaneously. (The four satellites are required to provide global coverage.) However, since early 1979, 5 DSCS II satellites are now operating, 3 have stopped operating, and 4 more have failed to achieve orbit.

Specifically, the first pair of DSCS II satellites were launched in November 1971 and provided Defense with Atlantic and west Pacific transoceanic communications service, but now they are not operational. In September 1972 one of these satellites suffered a power failure in orbit and consequently was terminated from operations. The other satellite continued to operate over the Atlantic Ocean until September 1973 when a power failure terminated its mission.

The second launch of DSCS IIs occurred in December 1973, which then provided a pair of spacecraft to replace the failed Atlantic and Pacific satellites. One of these satellites stopped operating in 1976, and the other one has been repositioned from the Atlantic to the Indian Ocean, where it is still operating. The third pair of DSCS IIs were launched in May 1975, but neither satellite achieved orbit.

The procurement of six more DSCS IIs was funded by Defense in 1974. The first pair of these were launched in May 1977 and they are presently providing service over the Atlantic and west Pacific Oceans. The next pair were launched in May 1978, but they never achieved orbit because of a launch vehicle failure. The third pair of this series were launched successfully in December 1978, and for the first time since 1969, Defense had a full complement of four DSCS II satellites (and a spare) in orbit. They were all operational in March 1979.

DSCS II satellites

The DSCS II satellites are significantly more complicated than the IDCSP satellites. However, they are about as complicated as the INTELSAT IV satellites. Figure 4 on page 38 shows a DSCS II satellite. Each one is about 13 feet high, weighs about 1,150 pounds at launch, and has an average design life of about 5 years. It has four communications channels using an overall bandwidth of about 500 megahertz. As the figure shows, the DSCS II satellites employ two Earth coverage horns and also two parabolic dish antennas for both narrow and spot 1/ beam coverage.

DSCS III

The third or next phase of the DSCS program (DSCS III) is concerned with providing global super-high frequency communications coverage for Defense through the 1980s. This series of satellites is expected to have improvements over the DSCS IIs in the areas of communications flexibility, reliability, and survivability.

In December 1974 the Deputy Secretary of Defense approved the first stage of the DSCS III program. The Defense Communications Agency was delegated overall responsibility for its management. In 1975, after a 1-year period of source selection, SAMSO selected the General Electric and Hughes Aircraft Companies as contractors to simultaneously fabricate bread

1/The narrow beam's coverage is wider than that of the spot beam.

board parts for the new satellite design--DSCS III. For about $7.5 million apiece, the two firms competed under separate contracts to provide a preliminary DSCS III design. In February 1977 SAMSO selected the General Electric Company to fully develop DSCS III satellites.

DSCS III satellites

The DSCS III satellites are much more complicated than the DSCS IIs. Each DSCS III is expected to be about 6 feet high and to weigh about 2,400 pounds at launch. Instead of being a spin-stabilized satellite, like the DSCS II, the DSCS III will be stabilized about its three axes of rotation. This means that the whole satellite will always be oriented in the Earth's direction, whereas the earlier DSCS IIs rotate about their own vertical axis and only their antennas' orientations are maintained toward the Earth. Figure 5 on page 39 shows the DSCS III satellite.

The DSCS IIIs will have four Earth coverage antennas, three multiple beam antennas, and one parabolic dish antenna. They will each have six communications channels. Nevertheless, they will still use the 500 megahertz bandwidth available to earlier military super-high frequency satellites. These satellites are being hardened to withstand the effects of nuclear attacks, and their design lives will be about 10 years.

FLTSATCOM

FLTSATCOM, a series of highly complicated satellites operating in the ultra-high frequency (UHF) band, is used to relay tactical and logistical communications among naval forces and to route high priority Air Force strategic and tactical communications among the Single Integrated Operations Plan forces. This joint service satellite system will provide the Navy with the 9 channels for relay of two-way fleet communications and 1 channel for one-way fleet broadcasts. The Air Force will use one wide band and 12 narrow band UHF channels for its high priority communications.

Since it utilizes portions of the FLTSATCOM satellites, the Air Force Satellite Communications (AFSATCOM) program did not require the development of a dedicated satellite. We are therefore limiting our discussion to the FLTSATCOM satellites. However, it is appropriate to consider the Air Force requirements that increased the complexity of these satellites.

The FLTSATCOM satellites were designed and developed by TRW, Inc. Overall responsibility for the program resides within the Navy and the satellite contracting activities are being managed by SAMSO.

The FLTSATCOM development contract was awarded to TRW in November 1972. This contract included provisions for engineering development, fabrication, and testing of one qualification model (unflyable) spacecraft. Although the production contract was awarded to TRW in July 1975, the development of the qualification model was not completed until May 1977.

The presently approved FLTSATCOM program consists of four synchronous-orbit satellites--to provide global coverage--and one spare. The number of satellites envisioned for this system has varied since the program's inception in 1972 from 5, to 3, to 7, to 9, to 11, and now back to 5. The final number was arrived at as a result of technical difficulties encountered with the development program that contributed to very large cost and schedule overruns and, as a consequence, from congressional guidance to Defense which asserted that the Navy should lease its follow-on service for its fleet's communications.

The Navy has awarded a contract to Hughes Aircraft Company for the lease of follow-on satellite service. SAMSO is not retaining contractual responsibility for this service.

The Navy has reduced the leased communications requirements to exclude the AFSATCOM programs. The Air Force has recently decided to satisfy these requirements with its own set of alternatives.

The first FLTSATCOM satellite was launched on February 9, 1978, aboard an Atlas/Centaur booster. The launch was successful and the satellite is presently operational. The next launch is scheduled for later in 1979.

FLTSATCOM satellites

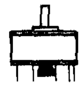
The FLTSATCOM satellite design is very complicated. It is about as complex as the DSCS III design. Figure 6 on page 40 shows one of these satellites. Each one uses a parabolic UHF transmit antenna and a deployable UHF receive antenna, which is mounted adjacent to the parabolic one. There are 10 channels for the Navy's communications and 13 channels for the Air Force's. The satellites are hardened for nuclear attacks and their design lives are about 5 years. They weigh about 4,100 pounds at launch and are about 21 feet high.

Figure 1

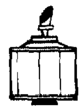
COMSAT AND COMSAT GENERAL SATELLITES

INTELSAT I (EARLY BIRD)

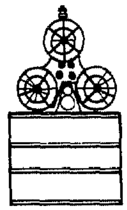
INTELSAT II



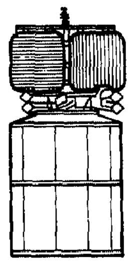
INTELSAT III



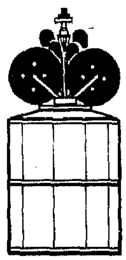
MARISAT



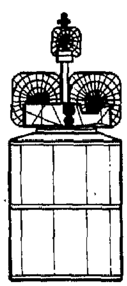
COMSTAR



INTELSAT IV



INTELSAT IV-A



APPENDIX II

Figure 2

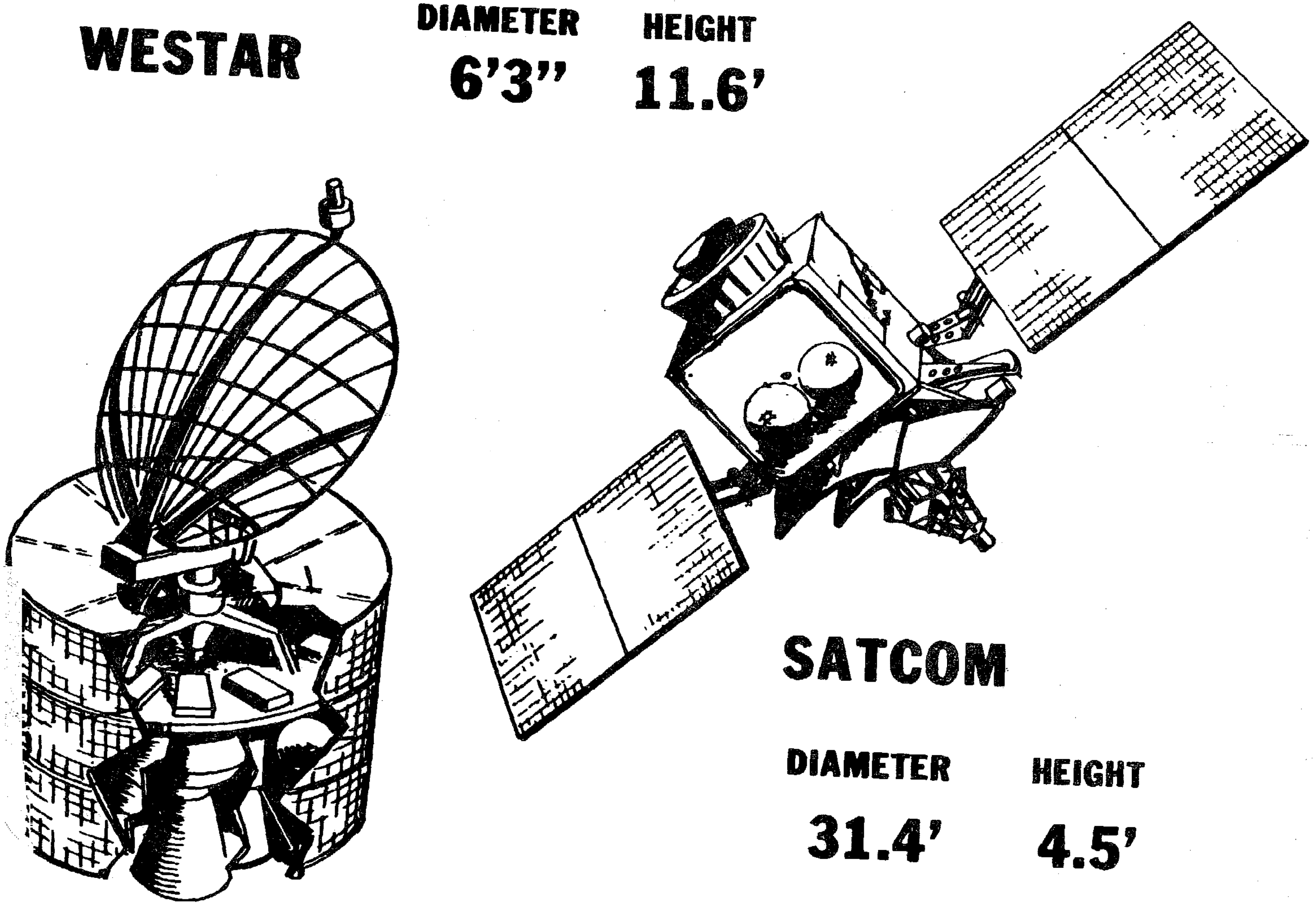
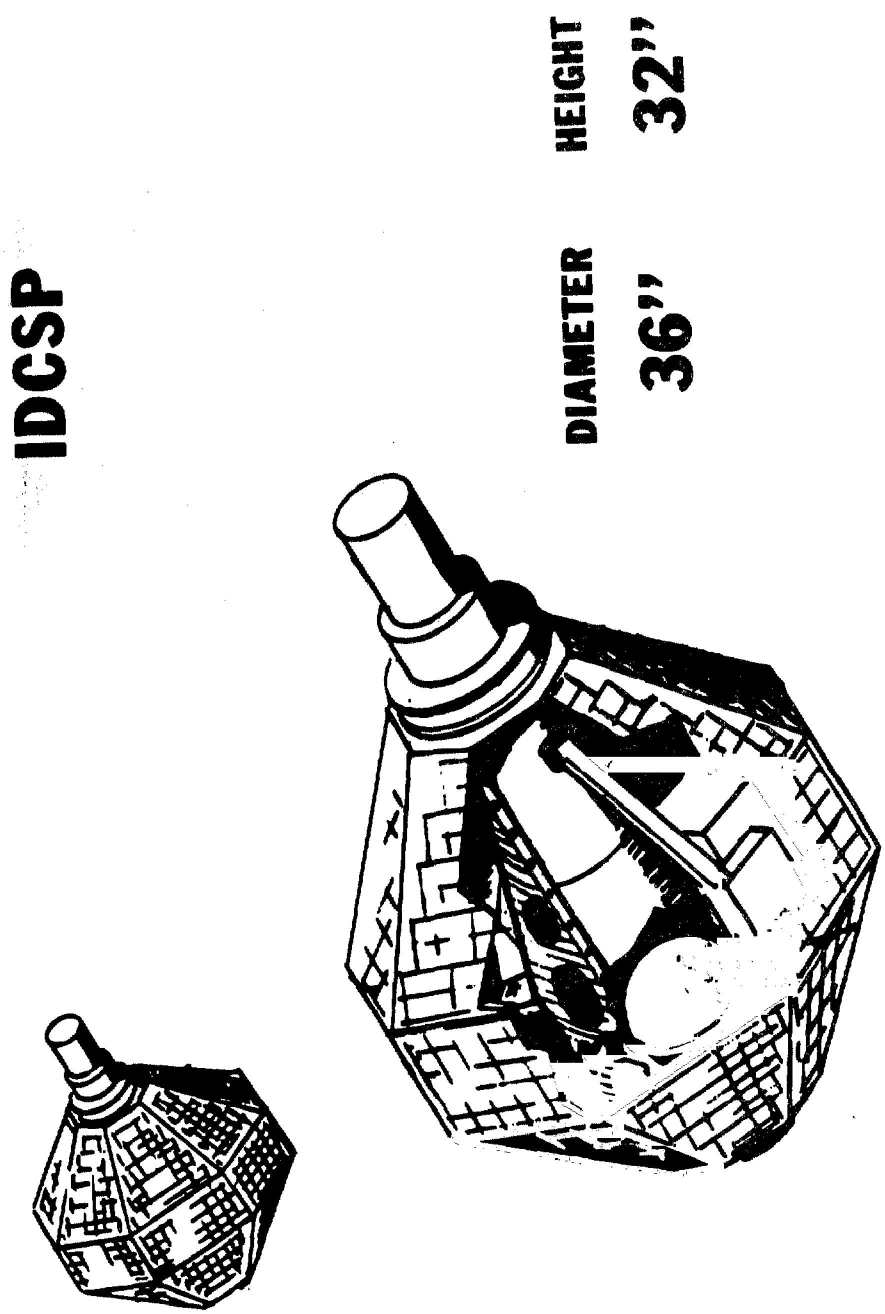


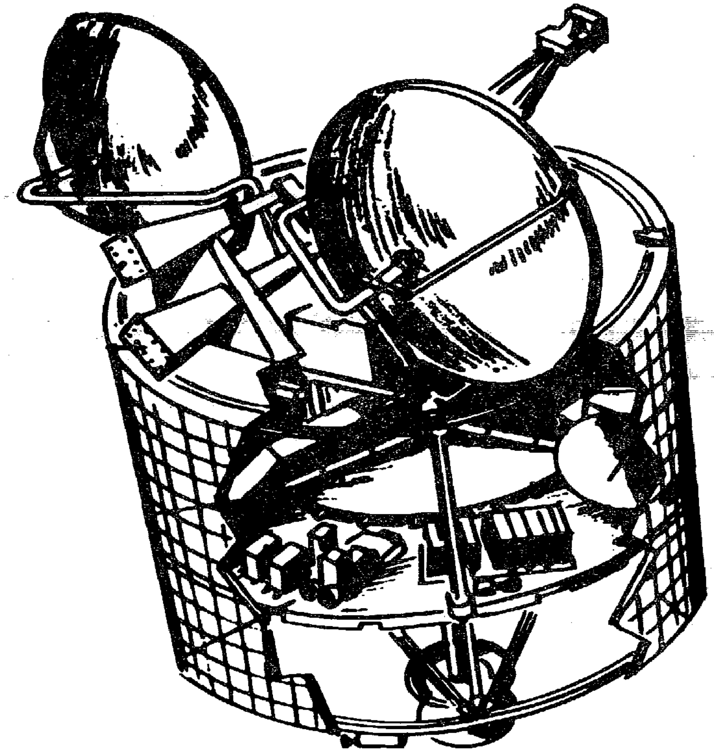
Figure 3



APPENDIX II

Figure 4

DSCS-2



DIAMETER **9'**

HEIGHT **13'**

APPENDIX II

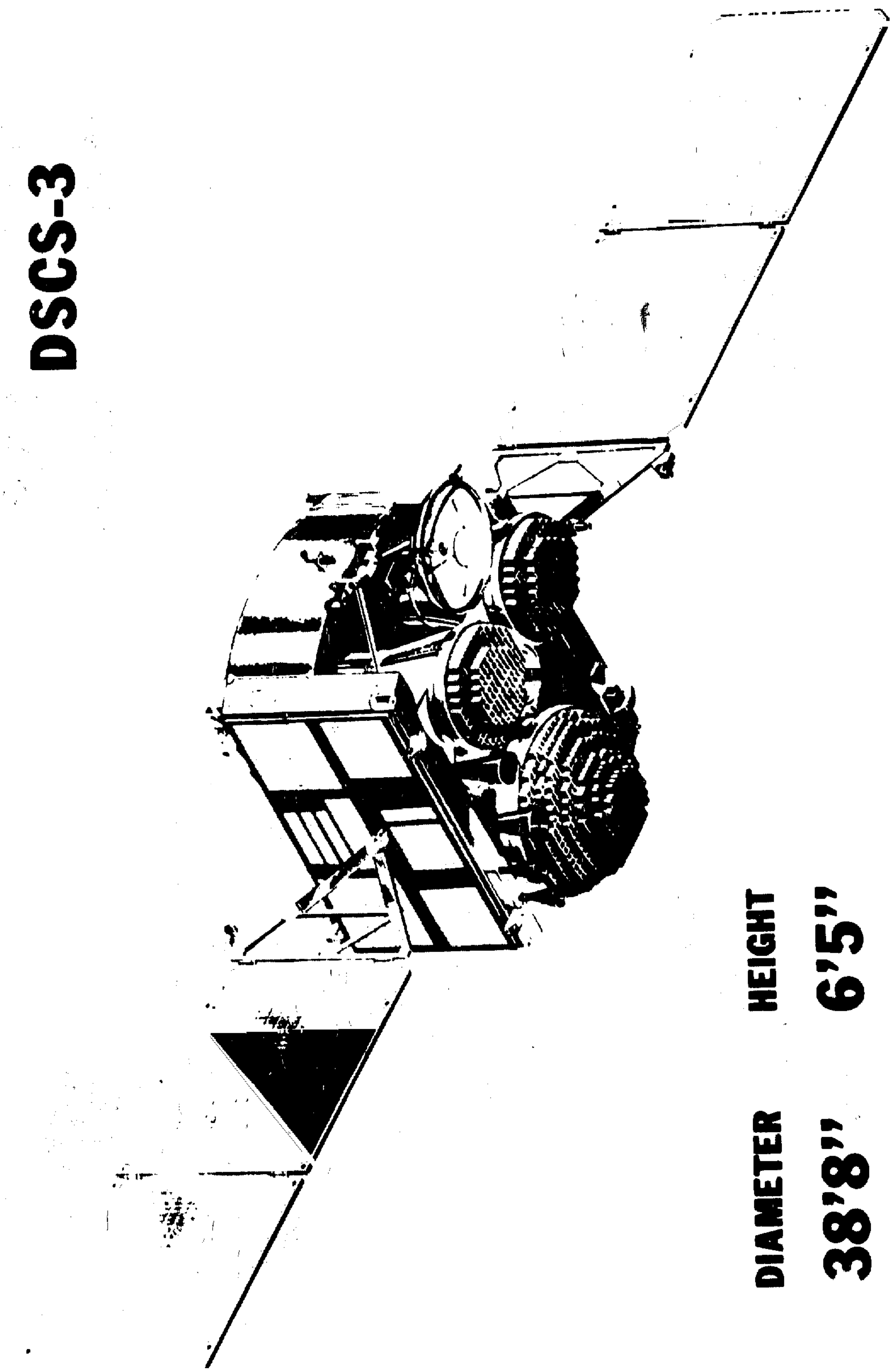


Figure 5

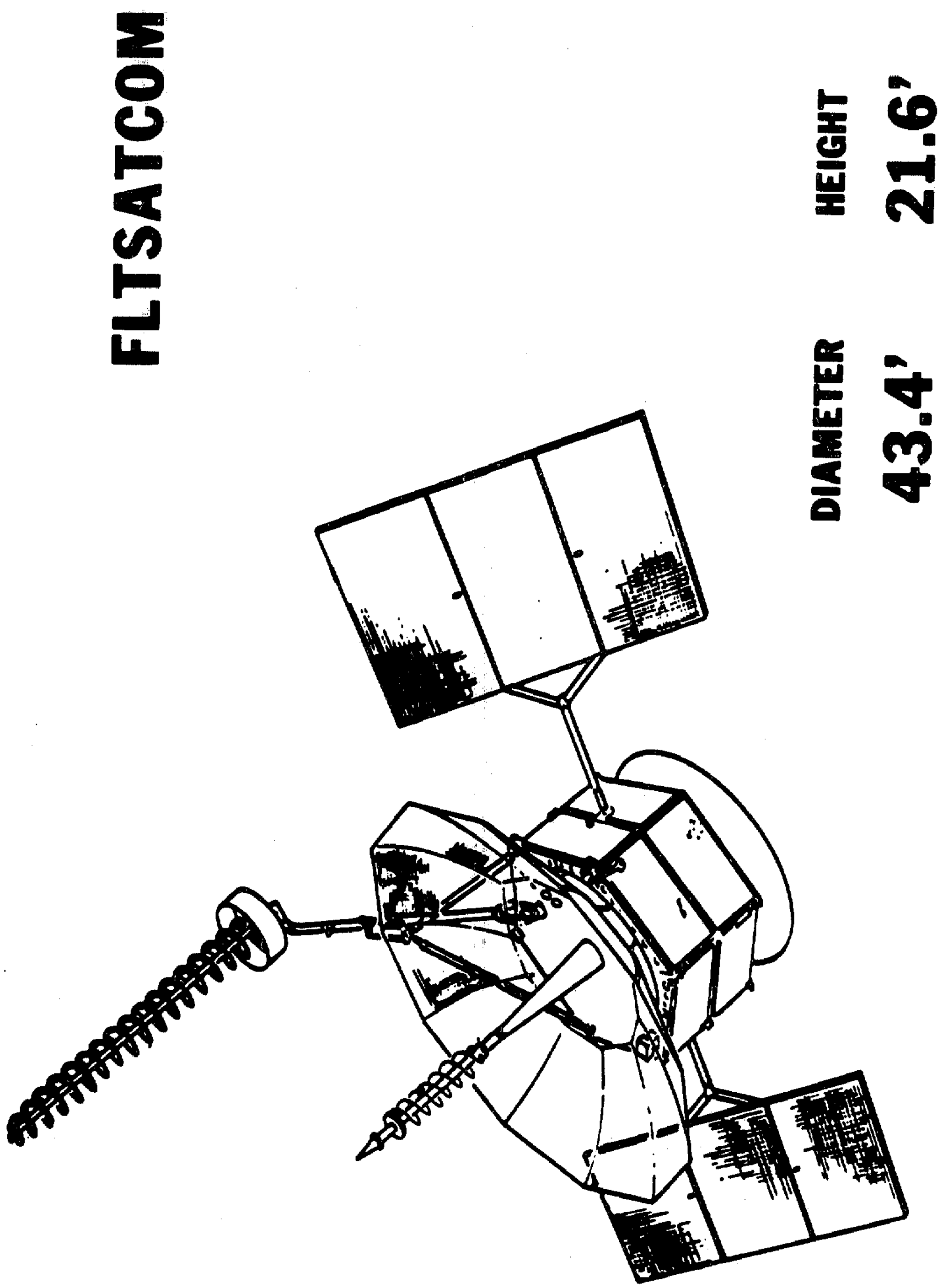


Figure 6

(941174)

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